Natural systems for onsite treatment are an alternative to mechanized treatment systems. Natural systems have the advantage of minimized operation and maintenance costs, but are often more difficult to control. Solar, aquatic, and plant based treatment systems depend primarily on their natural components to achieve the intended purpose. The types of systems to be discussed in this chapter are (1) surface flow constructed wetlands, (2) subsurface flow constructed wetlands, (3) ecological systems, (4) evapotranspiration systems, and (5) lagoons.

9-1 Constructed wetlands (surface flow)

Category	Secondary and tertiary treatment
Technology	Solar/aquatic treatment system
Input	Stormwater and secondary treated wastewater
Function	Removal of particulates, BOD, nutrients, and pathogens; effluent polishing
Applications	Agricultural, industrial, and domestic systems

Background
A wetland refers to land in which the water table is at, or above, the ground surface to maintain saturated soil conditions and growth of related vegetation. The use of constructed wetlands for the treatment of wastewater is becoming more common in urban and rural areas. These systems have been used for the treatment of wastewater from agricultural, industrial, municipal, and storm runoff wastewaters. The need to meet more stringent discharge requirements in the future may limit their application.

Description of process
A surface flow (SF) constructed wetland, also known as a free water surface (FWS) wetland, has a water level above the ground surface. It is a shallow natural treatment process that performs a combination of unit processes. Typical vegetation for SF systems includes cattails, reeds, sedges, and rushes. Native wetland vegetation can be found in all regions of the country and has the advantage of being well adapted to the climate. The vegetation is flooded with an effluent, normally pretreated in a septic tank. Seasonal patterns are of concern, due to the variability in primary productivity with changing climatic conditions. Design criteria for constructed wetland systems can be found in Crites and Tchobanoglous (1998), U.S. EPA (2000), and U.S. EPA (2002).

System footprint
The size of surface flow wetlands depends on the quality of the influent wastewater and the degree of treatment to be accomplished. Surface flow wetland systems typically require a large land area and should be designed by a qualified organization. Depending on the type of soil, depth to groundwater, and other site specific conditions, a clay or synthetic liner may be needed.

Advantages
Can be used to improve water quality and provide wildlife habitat. Relatively low technology systems that utilize a long hydraulic residence time (HRT) and passive solar energy to achieve treatment.

Disadvantages
If improperly designed or maintained, nuisance conditions may result. Surface flow wetlands are a potential vector for mosquito propagation. In summer months, algae in the effluent can result in high TSS concentrations.

Performance

Expected effluent quality from surface flow constructed wetlands are presented in Table 9-1. In addition to the water quality parameters listed in Table 9-1, wetland systems have also been found to sequester metals and reduce pathogens in wastewater.

Table 9-1

Typical performance of surface flow wetlands[a]

Parameter	Effluent value
BOD_5	<20 mg/L
TSS	<20 mg/L
TN	<10 mg/L
TP	<5 mg/L
Fecal coliform	2 to 3 log removal

[a] Adapted from Crites and Tchobanoglous (1998).

Operation and maintenance

Minimal maintenance is needed for wetland systems and, in many cases, maintenance may be performed by non-skilled personnel or the system owner. Periodic removal and thinning of vegetation may enhance hydraulic performance. A fence around the facility may be needed to meet safety concerns.

Power and control

Power and control systems are not needed unless water will be pumped to an elevated location.

Cost

A surface flow wetland system for an individual home will typically cost from $2,000 to 5,000, depending on the degree of pretreatment and site conditions.

Figure 9-1

A surface flow wetland for stormwater runoff treatment in an urban area. Note walkway and signs located around facility to educate community about non-point source pollution and treatment system. (Photo of Tollgate wetlands by CR MacCluer.)

References and other resources
Crites, R., and G. Tchobanoglous (1998) *Small and Decentralized Wastewater Management Systems*, WCB/McGraw-Hill, New York.

U.S. EPA (2000) *Constructed Wetlands Treatment of Municipal Wastewaters*, EPA/625/R-99/010, Office of Research and Development, United States Environmental Protection Agency, Wachington, DC.

U.S. EPA (2002) *Onsite Wastewater Treatment Systems Manual*, EPA/625/R-00/008, Office of Water, Office of Research and Development, United States Environmental Protection Agency, Wachington, DC.

9-2 Constructed wetlands (subsurface flow)

Category	Primary and secondary treatment
Technology	Solar/aquatic treatment system
Input	Primary and secondary effluent
Function	Removal of particulates, BOD, nutrients, pathogens
Applications	Agricultural, industrial, and domestic systems

Background
The subsurface flow (SSF) constructed wetland system is composed of a bed of gravel or other aggregate packing material contained in a lined bed. Subsurface flow systems are often used for the treatment of wastewater that has a high concentration of biodegradable organic material because the treatment process is primarily anaerobic. Subsurface flow wetlands offer several advantages over other surface flow wetlands; however, the need to import packing material significantly increases the cost of subsurface flow constructed wetlands.

Description of process
In a subsurface constructed system, the water to be treated flows through a porous packing material. The packing material has sufficient depth so that the water is not seen from the surface. The vegetation of the wetland provides some oxygen to the root zone and provides surface area for biological growth. The vegetation also stabilizes the bed surface, prevents the bed from freezing, and improves the wetland aesthetics. Mixed cultures of wetland vegetation typically provide a more stable and effective wastewater treatment process. An outlet device is used to control the depth of water in the wetland.

System footprint
The typical constructed subsurface wetland system has a slope of approximately 0 to 0.5%, and an impermeable liner membrane on the bottom to prevent leakage to the groundwater. The depth of the bed ranges from 1.5 to 3.3 ft. The typical size for a single household system is 300 to 400 ft^2. The treatment system is temperature dependent and requires a larger area for a colder climate. The expected effluent concentrations of BOD_5 and TSS are 5 to 10 mg/L and 10 to 20 mg/L, respectively.

Advantages
Subsurface flow wetlands are able to treat wastewater with high concentrations of COD, such as that from food processing facilities, breweries, and wineries. Subsurface flow wetlands typically have a higher removal rate of BOD_5, TSS, and nitrogen than surface flow systems. Because the water is contained within the gravel media, there is reduced chance for public exposure to wastewater and mosquito breeding. Vegetation can be integrated into landscape and add aesthetic appeal. In addition, the subsurface flow wetland is a relatively passive process that does not require forced aeration.

Disadvantages
The aggregate packing material used may be expensive to acquire in some areas. There is limited process control relative to other types of treatment processes once the system is installed. The potential for the periodic release of adsorbed constituents is also of concern.

Performance
Expected performance of subsurface flow constructed wetlands is presented in Table 9-2. In addition to the parameters and values listed in Table 9-2, wetlands are also known to sequester metals. Low effluent phosphorus concentrations can be obtained when a phosphorus adsorbing medium is used.

Table 9-2
Typical performance of subsurface flow wetlands[a]

Parameter	Effluent value
BOD_5	<20 mg/L
TSS	<20 mg/L
TN	<10 mg/L
TP	<5 mg/L
Fecal coliform	2 to 3 log removal

[a] Adapted from Crites and Tchobanoglous (1998).

Operation and maintenance
Operation and maintenance for a subsurface system are minimal, although the surface growth may need to be cut back. The system should not be a source of odors, while the effluent is introduced below the surface. A small observation tube should be installed in each cell so the homeowner can periodically check the water level to ensure that it is not too low or too high. Plant care may also be needed, such as removing dead plants and any weeds or saplings that have taken root.

Power and control
Subsurface flow constructed wetlands generally do not require power or control systems to operate.

Cost
Subsurface flow systems cost significantly more than surface flow systems because they are more difficult to design and they often require the importation of a suitable gravel substrate. The costs for a subsurface system, including a septic tank pretreatment system can range from $10,000 to 15,000 for an individual home. Each wetland design and cost will differ based on soil conditions, usage requirements, and local and state laws.

Figure 9-2
Onsite treatment of septic tank effluent in a subsurface flow constructed wetland. (Adapted from IEES, 2001.)

References and other resources

Crites, R., and G. Tchobanoglous (1998) *Small and Decentralized Wastewater Management Systems*, WCB/McGraw-Hill, New York.

IEES (2002) EcoEng Newsletter 1, April 2002, *International Ecological Engineering Society*.

U.S. EPA (1993) *Subsurface Flow Constructed Wetlands for Wastewater Treatment: A Technology Assessment*, EPA/832/R-93/001, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

U.S. EPA (2000) *Constructed Wetlands Treatment of Municipal Wastewaters*, EPA/625/R-99/010, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

U.S. EPA (2002) *Onsite Wastewater Treatment Systems Manual*, EPA/625/R-00/008, Office of Water, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

9-3 Ecological systems

Category	Secondary and tertiary treatment
Technology	Aquatic treatment systems
Input	Primary treated wastewater
Function	Organic, nutrient, and pathogen removal, effluent polishing
Applications	Small community, institutional, commercial, and industrial systems

Background/description of process

Ecological or solar aquatic systems are greenhouse based wastewater treatment systems. The entire treatment system is contained in a greenhouse to sustain year-round operation. The water to be treated flows through different biosystems (anaerobic, anoxic, aerobic, vegetated, etc.), where plants, algae, and other organisms remove BOD, TSS, nutrients, and pathogenic organisms.

System footprint

Ecological wastewater treatment systems are typically contained in greenhouse or atrium structures. The size requirements depend on the wastewater quality and quantity to be treated. In milder climates, the treatment reactors may not require a greenhouse.

Advantages

Ecological systems are an aesthetically pleasing and effective treatment system that is often used to educate people about waste and wastewater.

Disadvantages

Ecological systems are typically more expensive than other treatment processes because of the custom design for each application and additional space and structural needs.

Performance

The performance of ecological treatment systems is presented in Table 9-3.

Operation and maintenance

Ecological wastewater treatment systems require regular inspection and maintenance of the treatment process and the vegetation; however, because these systems are typically more visible than other underground treatment processes, monitoring activities may be easier.

Power and control

Systems can employ passive or active aeration. The power requirements will depend on the amount of aeration and pumping utilized in the treatment process.

Table 9-3

Expected performance of ecological wastewater treatment systems[a]

Parameter	Effluent concentration, mg/L
BOD	<5
TSS	<5
TN	<10
TP	<5

[a] Adapted from Crites and Tchobanoglous (1998).

Figure 9-3

Ecological wastewater treatment systems contained in greenhouse structures and treating domestic wastewater. (Adapted from Ocean Arks International and EcoWerks Technologies.)

Contact

The following organizations can provide engineering and design consulting on ecological wastewater treatment systems.

9-3.1 EcoWerks Technologies

100 Arbors Lane, Unit A
Woodbridge, ON L4L 7G4 Canada
Phone (905) 856-5225 x33
Fax (905) 856-9017
E living@ecowerks.ca
Web www.ecowerks.ca

9-3.2 Living Technologies

125 La Posta Rd., 8018 NDBCU
Taos, New Mexica 87571
Phone (505) 751-4448
Fax (505) 751-9483
E info@livingmachines.com
Web www.livingtechnologies.com

9-3.3 Ocean Arks International

176 Battery Street
Burlington, VT 05401
Phone (802) 860-0011
Fax (802) 860-0022
E info@oceanarks.org
Web www.oceanarks.org

9-3.4 Solar Aquatics Systems

508 Boston Post Rd.
Weston, MA 02493
Phone (781) 891-5085
Fax (781) 891-8654
E eea@solaraquatics.com
Web www.solaraquatics.com

9-4 Evapotranspiration (ET) systems

Category	Soil treatment/atmospheric discharge
Technology	Evapotranspiration
Input	Primary or secondary treated wastewater
Function	Wastewater evaporation
Applications	Residential systems

Background

Evaporation and evapotranspiration (ET) systems dispose of wastewater to the atmosphere through evaporation from the soil or transpiration from plants. The system is an option for arid and semi-arid areas where the annual evaporation is higher than the precipitation, for sites where protection of the surface water and groundwater is essential, or where other limiting site conditions will not allow soil discharge of wastewater.

Description of process

Wastewater pretreated in a septic tank or secondary treatment device flows into a bed lined with an impermeable membrane and filled with sand. Vegetation planted on the surface of the bed enhances the transpiration process. The water rises up to the surface by capillary forces in the sand and evaporates. The vegetation transports the water from the root zone to the leaves, where it also evaporates. When the water evaporates, salts, minerals and solids accumulate in the bed. The evapotranspiration bed surface area is often divided into two parts to make it possible to switch between them to avoid overloading.

System footprint

A liner and/or clay layer is placed in the bottom of an excavated bed. A layer of gravel or rock with a diameter of 0.75 to 2 in and a depth of 12 in, depending on the bed's total depth, is placed within the liner. A crown of topsoil may be placed on the sand bed to enhance plant growth and the rate of evaporation. Systems are sized according to local climatic conditions and the quantity of wastewater to be evaporated. The typical surface area required for an ET system is 1,000 to 2,000 ft^2.

Advantages
The risk of groundwater contamination is minimized with an ET system that has an impermeable liner. An ET system is ideal for seasonal applications, especially for summer homes or recreational parks with high evaporation and transpiration rates, such as in the southwestern U.S. Landscaping enhances the aesthetics of an ET system.

Disadvantages
The ET system is not suitable in areas with land limitations due to the space requirements for these systems. They have a limited storage capacity, and are generally not designed to store winter wastewater for evaporation in the summer. The transpiration and evaporation rate is somewhat dependent on the vegetation. Salt accumulation and other elements can have a negative effect on vegetation. The system may be affected by excess precipitation.

Performance
The amplitude for the ET cycle is latitude dependent with larger variations for larger latitudes. While the evapotranspiration is solar driven, the system is also dependent on a diurnal cycle, in which the maximum water loss is at mid-day and the minimum is almost zero in the middle of the night. The performance of an ET system is largely affected by climate factors, such as precipitation, temperature, and wind speed. Other factors that determine the performance are water usage, potential for capillary rise, and the ability of cover soil and vegetation to withstand fluctuating precipitation.

Operation and maintenance
To maintain the system it is important to mow the grass regularly and have a yearly cover. A small slope will help the rain run off the bed, and avoid overloading. The bed should be designed to eliminate the possibility of clogging.

Power and control
Evapotranspiration systems are solar powered and do not require supplemental power or control systems to operate.

Cost
The construction cost of an ET system depends on the surface area and the characteristics of the wastewater. Other cost considerations are availability of sand, thickness of liner and type of vegetation. Estimated costs range from $6,000 to $10,000 for design and installation of the ET bed, in addition to the cost of pretreatment devices.

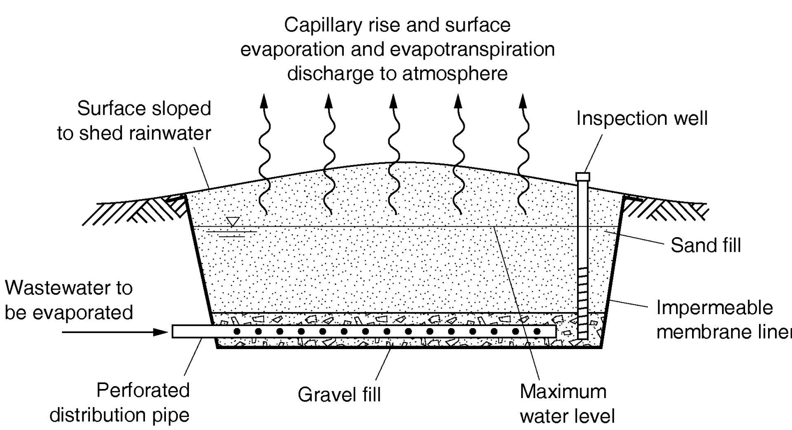

Figure 9-4

Diagram of an ET system for wastewater evaporation.

References and other resources
U.S. EPA (2000) *Decentralized Systems Technology Fact Sheet: Evapotranspiration*, EPA/832/F-00/033, Office of Water, United States Environmental Protection Agency, Wachington, DC.

9-5 Lagoons

Category	Secondary and tertiary treatment
Technology	Solar/aquatic treatment system
Input	Stormwater and primary or secondary treated wastewater
Function	Removal of particulates, BOD, nutrients, and pathogens
Applications	Agricultural, industrial, and domestic systems

Background/description of process
Lagoons are artificial ponds built into the ground, or above the ground with earthen dikes, to treat wastewater. There are four basic types of systems: *anaerobic, facultative, aerated lagoons*, and *stabilization ponds*. The type of lagoon varies according to the amount of dissolved oxygen typically present in the water, which is dependent on the loading rate and other design parameters. The purpose of treatment lagoons is to receive, retain, and treat wastewater for an extended period of time.

Anaerobic lagoons
In an anaerobic system, the bacteria responsible for the breakdown of organics are able to operate in the absence of both free oxygen and oxygen contained in inorganic compounds. Anaerobic ponds serve as sedimentation basins and anaerobic treatment systems. The two major steps in the process are the conversion of complex organic compounds to organic acids and the breakdown of the acids to carbon dioxide and methane. The anaerobic reactions take place in the sludge layer of the ponds. Intermediate organic acids are released to the water column and gas rises to the surface and is released to the air. Anaerobic lagoons are typically deep systems, up to 20 feet with steep sidewalls. Anaerobic lagoons develop a thick crust on the surface, which inhibits oxidization and serves to trap in heat, making anaerobic lagoons suitable for colder climates. Anaerobic lagoons can be expected to remove 60 percent of particulate material and 35 percent of the BOD; however, at low environmental temperatures anaerobic activity is significantly reduced.

Facultative lagoons
Facultative lagoons have an aerobic top layer and an anaerobic bottom layer. They tend to be large and shallow (3-8 feet) to allow for maximum diffusion of oxygen, which occurs at the surface, and to maximize algae growth. Algae help the treatment process by supplying oxygen through photosynthesis and by using nutrients in the wastewater. Facultative lagoons cause fewer odor problems than anaerobic systems, but may have problems functioning during prolonged cold periods when ice forms on the surface.

Aerobic lagoons (oxidation ponds)
Aerobic ponds have dissolved oxygen throughout most of the water column. Aerobic lagoons are shallow to allow oxygen and solar radiation to move through the water column. The ponds need to be mixed to prevent algae from forming a layer that blocks out the air and sun. The algae can be harvested and used as a component of animal food, as a soil conditioner, or for aquaculture projects. Aerated lagoons create aerobic conditions through mechanical means. Mechanical aeration allows these lagoons to use 60 to 90 percent less land area than non aerated stabilization ponds. Mechanical aeration can reduce the land area needed and initial construction costs, but will ultimately be more costly to operate and maintain.

Stabilization ponds
Stabilization ponds are the shallowest of all lagoon systems, typically only 2 feet deep. Stabilization ponds are passive systems that rely on the surface diffusion of oxygen and algae

growth to oxygenate the wastewater. Stabilization ponds require a large area of land, typically about 1 acre for every two hundred people, and are usually located in areas where the climate permits year round algae growth. Stabilization ponds are frequently used to treat dairy farm wastewater. Waste stabilization ponds achieve high removal of BOD and suspended solids, but the effluent quality is variable both between different systems and over time. The limiting factor for treatment of dairy wastewater is the low rate of nitrification.

System footprint
The system requires a large area compared to other treatment systems, especially in colder climate when the treatment process is less efficient and need a longer detention time.

Advantages
Pond systems can be cost effective where land is inexpensive. They are easy to operate and maintain and handle shock loadings better than many other systems. Because of a high nutrient level the effluent can be suitable for irrigation.

Disadvantages
Odor production may be a problem if the system is close to a populated area. The ponds can provide a breeding area for mosquitoes.

Performance
Effluent constituent concentrations are highly variable depending on the type of treatment systems, environmental conditions, and the influent water quality. Typical effluent BOD and TSS concentrations are in the range of 15 to 40 mg/L and 30 to 100 mg/L, respectively.

Operation and maintenance
Sludge accumulation will occur on the bottom and should be measured each year and removed as needed. A weed and vector control program should also be implemented to control nuisance conditions.

Power and control
Systems with mechanical aeration and mixing require power and control systems, significantly increasing the operational costs of these systems.

Figure 9-5

A stabilization pond treating wastewater from a cannery operation.

References and other resources

Crites, R., and G. Tchobanoglous (1998) *Small and Decentralized Wastewater Management Systems*, WCB/McGraw-Hill, New York.

U.S. EPA (1983) *Municipal Wastewater Stabilization Ponds - Design Manual*, EPA-625/1-83-015, Office of Water, United States Environmental Protection Agency, Washington, DC.